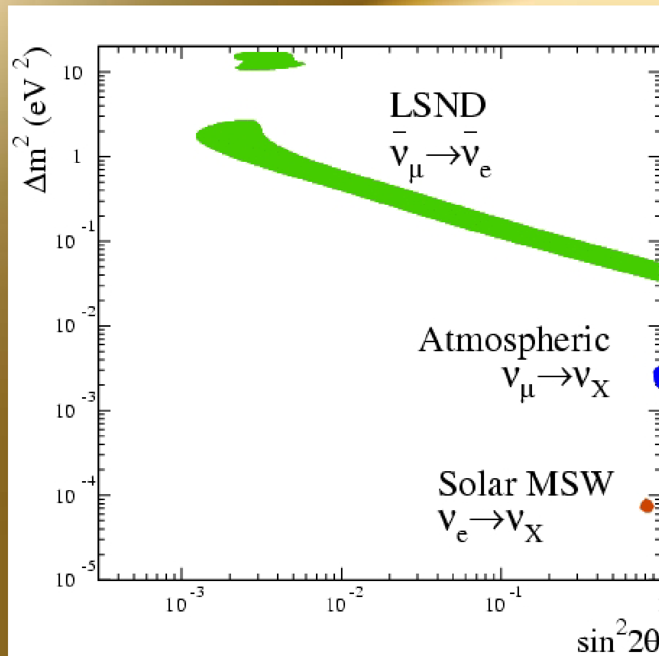
Neutrino Physics at MiniBooNE

Sam Zeller
Columbia University
PHENO 2004

1. Motivation and Overview
2. Latest Physics Results
3. Updated Sensitivity

Motivation: Three Signal Regions

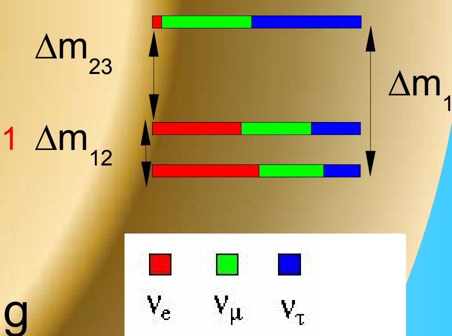


3 exp'l signatures for ν oscs point to 3 independent mass splittings

LSND: $\Delta m^2 \sim 0.1\text{-}10$ eV^2

Atmospheric: $\Delta m^2 \sim 10^{-3}$ eV^2

Solar: $\Delta m^2 \sim 10^{-5}$ eV^2



3 ν 's allows only 2 indep values of Δm^2: $\Delta m^2_{21} + \Delta m^2_{32} = \Delta m^2_{31}$

3 distinct oscillation signals with $\Delta m^2_{sol} + \Delta m^2_{atm} \neq \Delta m^2_{LSND}$

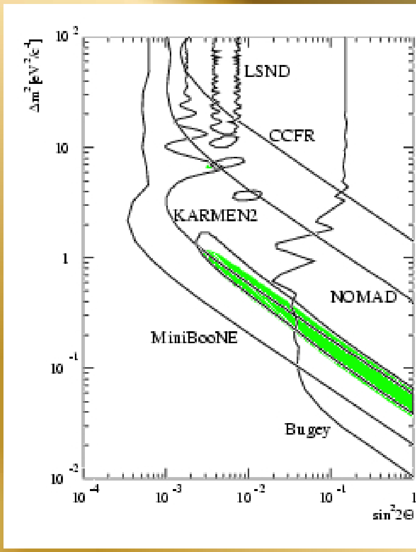
- one of the experimental measurements is wrong
  (or one or more are not seeing ν oscillations)
- additional sterile ν involved in the oscillation
  (>3 neutrinos gives 3 independent Δm^2 scales)
- or CPT is not a good symmetry
  (yields different mass scales for ν, $\bar{\nu}$)

Motivation: the LSND Result

* observed 3.8σ excess of $\overline{\nu}_e$ in $\overline{\nu}_\mu$ beam
evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations

87.9 ± 22.4 ± 6.0 excess
$P(\overline{\nu}_\mu \rightarrow \overline{\nu}_e) = (0.264 \pm 0.067 \pm 0.045)$ %

* unconfirmed by other experiments
but not excluded →

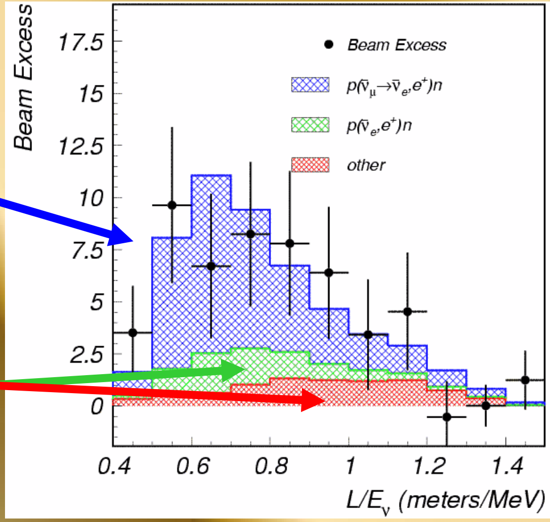


Church *et al.*, PRD 66, 013001 (2002)

joint LSND/KARMEN analysis leaves large allowed region compatible with both experiments

fit to oscillation hypothesis

beam-off and ν backgrounds



excess consistent w/ oscillations

To check LSND want:
- * same L/E, but …
- * higher statistics
- * different systematics
- * different signal signature & backgrounds

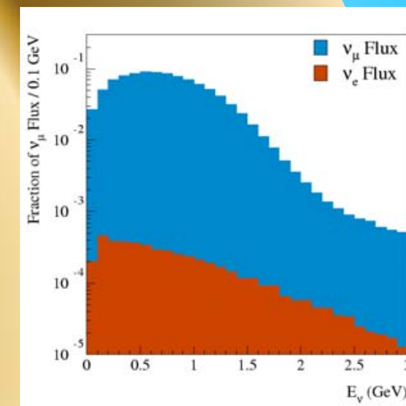
→ **MiniBooNE**
is that definitive test
search for $\nu_\mu \rightarrow \nu_e$ oscillations

designed a beamline & detector optimized for this direct search …

MiniBooNE Beamline

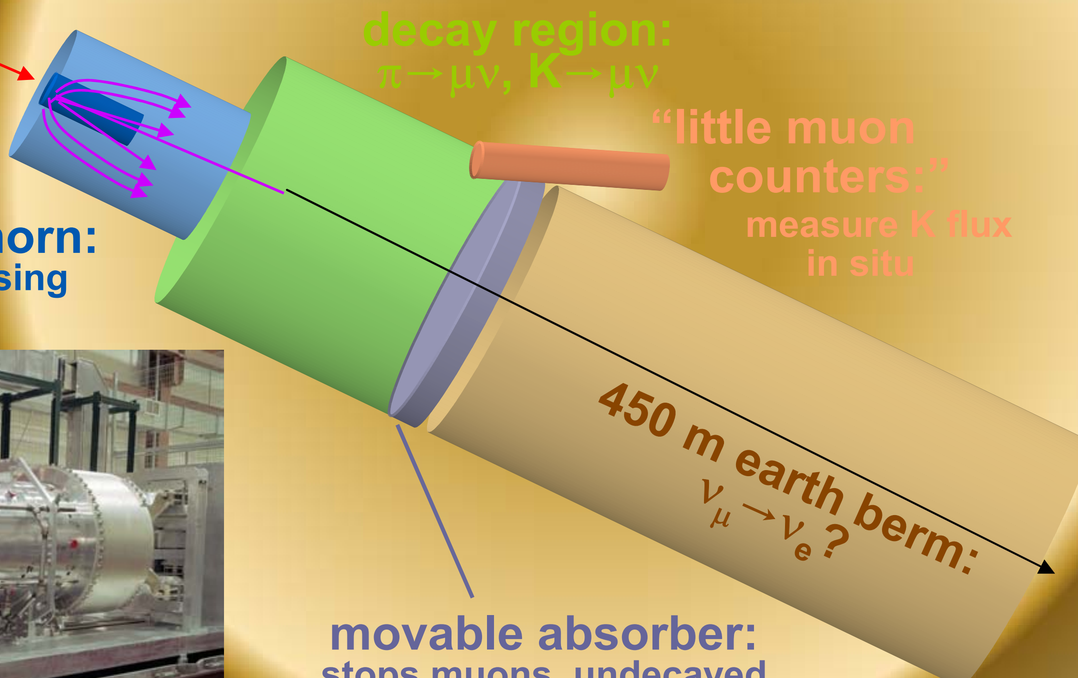
FNAL 8 GeV Booster

50 m decay pipe



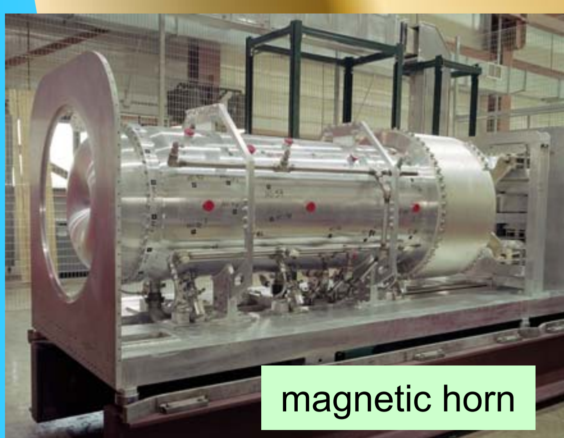
$<E_n>$ ~ 700 MeV

ν_e/ν_μ ~ 6 x 10^{-3}



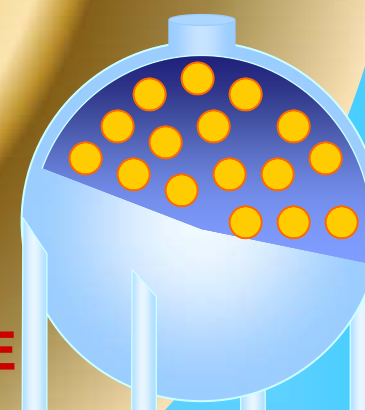
magnetic horn:
meson focusing

movable absorber:
stops muons, undecayed mesons



magnetic horn

technically the most impressive component of MiniBooNE



MiniBooNE detector

Sam Zeller, PHENO, April 26, 2004

Neutrino Events

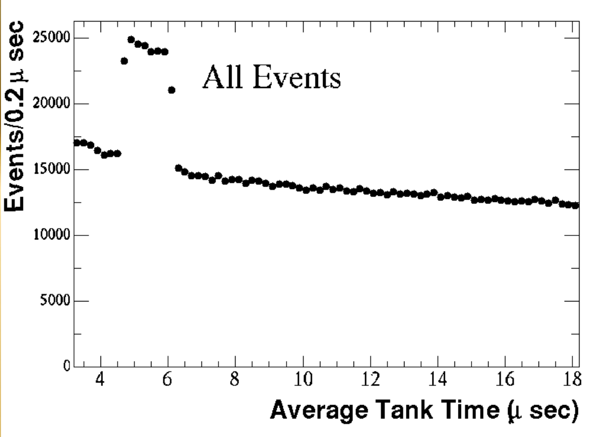
no high level analysis
needed to see
ν events
over background

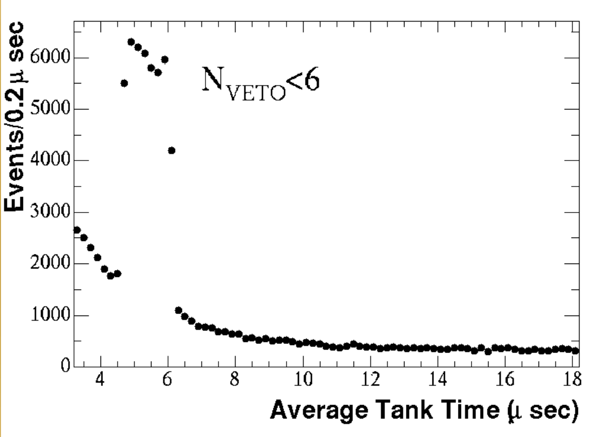
- collect events in 19.2μs window around every beam spill
- see clear excess during 1.6μs expected arrival of ν beam

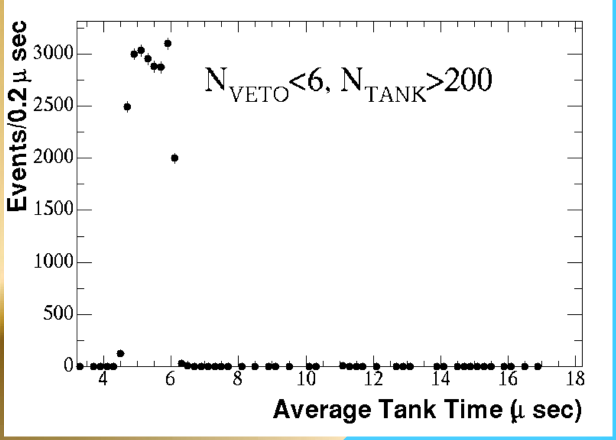
simple cuts reduce
non-beam background
to ~1/1000

current collected data:

~260,000 ν candidates
for 2.3 x 10^{20} POT

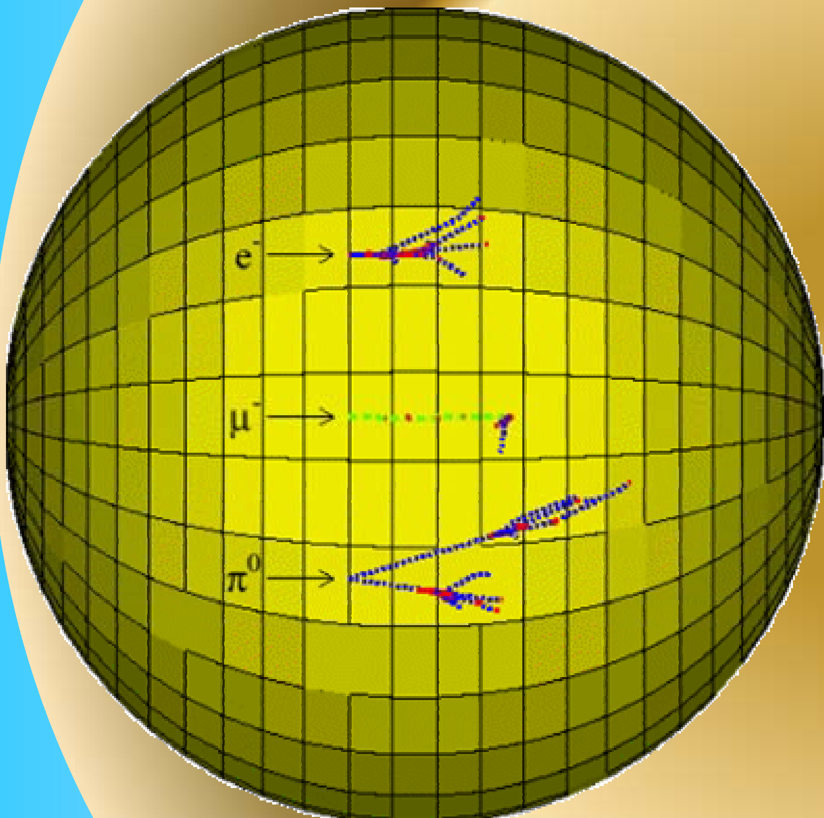


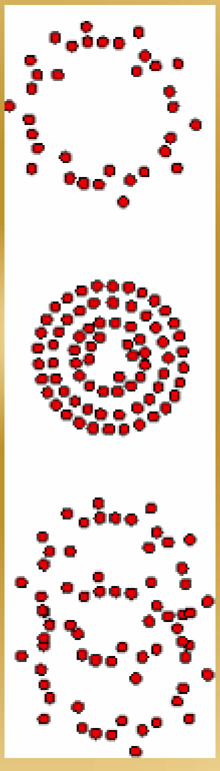




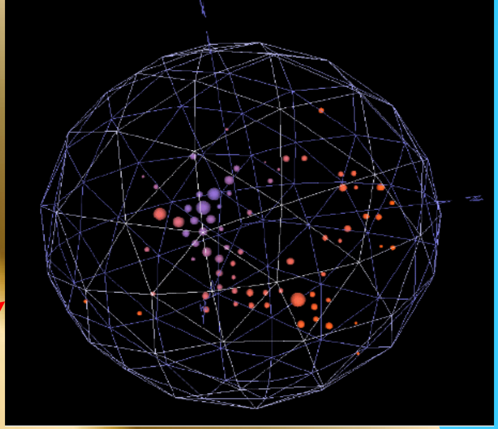
MiniBooNE Particle ID

Cerenkov rings provide primary means of particle identification

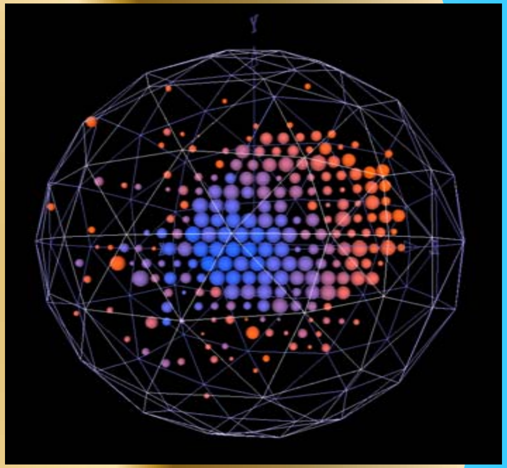




Michel e^- candidate



Beam μ candidate



Beam π^0 candidate

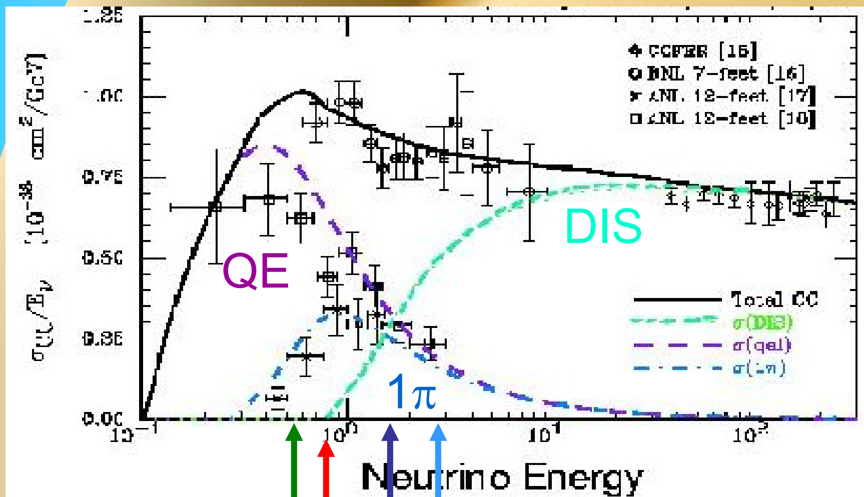
$\pi^0 \rightarrow \gamma\,\gamma$

neutrino interactions in detector produce particles we can detect

Latest MiniBooNE Results

coupling this type of PID with reconstruction packages, σ MC, full detector simulation

there is a lot of interesting physics on the path to oscillation results …



MINOS

K2K

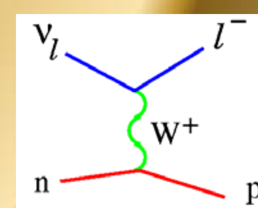
MiniBooNE

atmospheric ν

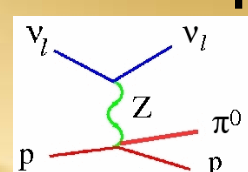
MiniBooNE will help improve our understanding of low E ν interactions on heavy targets

- imperative to ensure success of future generation ν osc exps
- MiniBooNE statistics will exceed any other exp in this E range
- these analyses are interesting in their own right

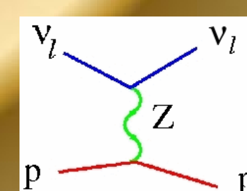
(1) ν_μ charged current quasi-elastic (QE)



(2) **π^0 events**

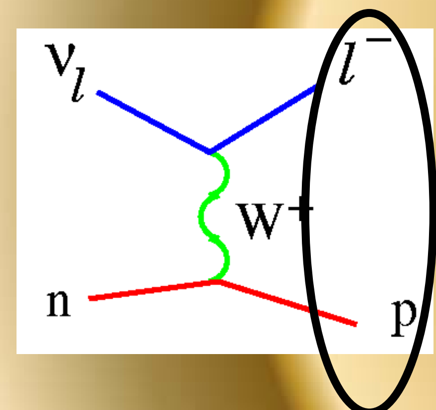


(3) neutral current elastic scattering



(distributions in all cases relatively normalized)

ν_μ CC Quasi-Elastic Events



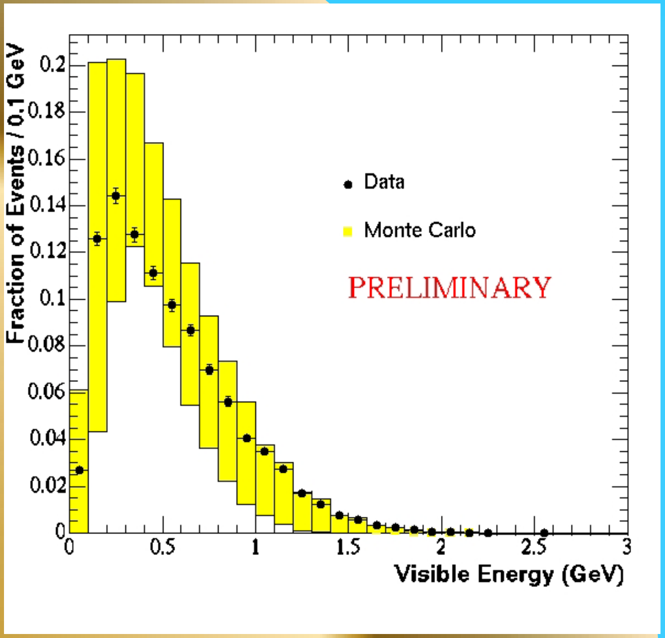
$\nu_\mu\, n \rightarrow \mu^- p$

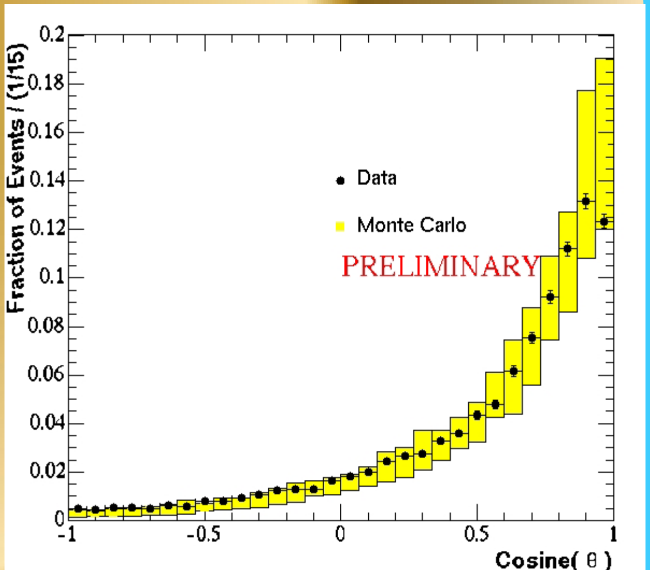
measure visible E and θ_μ from mostly Cerenkov (μ) + some scintillation light (p)

* 88% purity
* 30% efficiency

high statistics ~60k QE events now

(~ 30k shown in these plots)



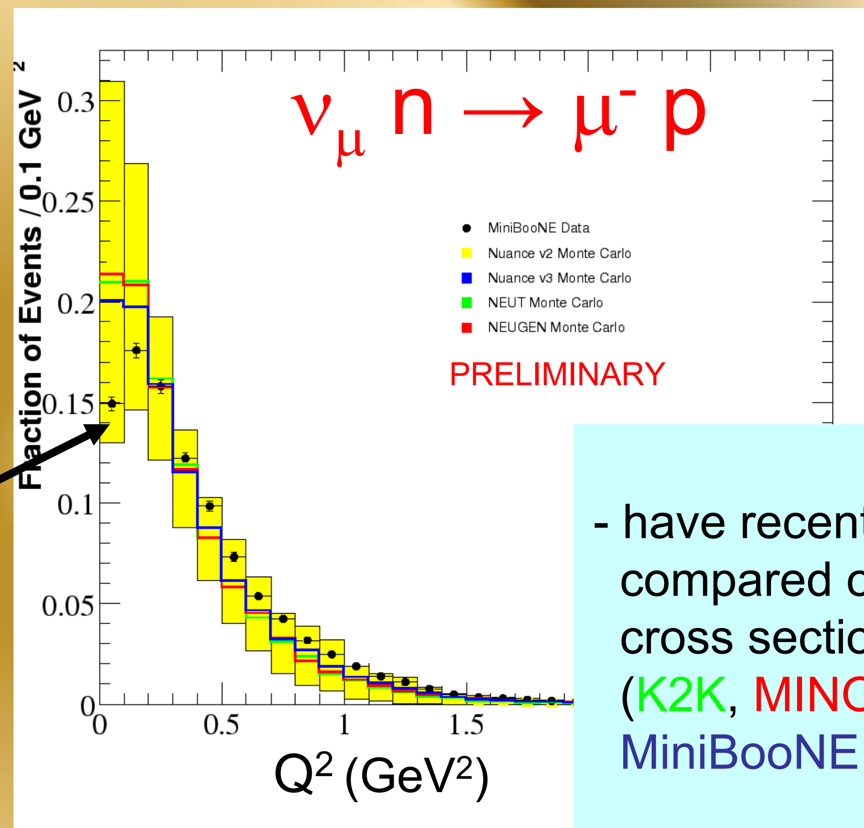


measured dists agree well w/ expectations

syst error band includes current flux, cross section, detector & optical model uncertainties

ν_μ CC Quasi-Elastic Events

$Q^2 = m_\mu^2 - 2E_\nu(E_\mu - p_\mu \cos\theta_\mu)$



- nuclear effects depend strongly on Q^2, so low Q^2 region provides information on modeling of nuclear effects in carbon

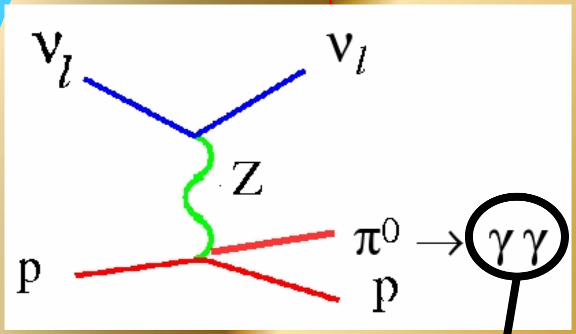
- interesting roll-over in data not tracked by Monte Carlo; also seen in K2K near detector data
  - received a lot of attention at recent NuInt04 workshop
  - points to a common model deficiency?

- have recently compared other cross section MCs (K2K, MINOS) to MiniBooNE data

- providing useful feedback to other ν experiments

NC π^0 Sample

ν_μ N $\rightarrow$ ν_μ N π^0

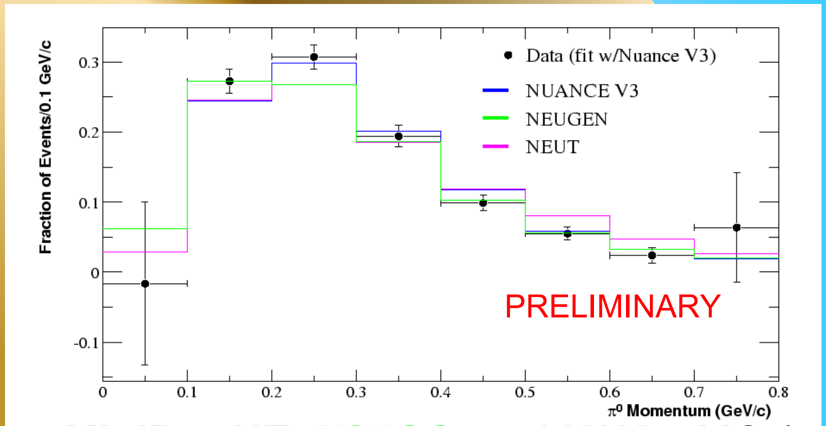


2 ring fit
determine E, direction of each Cerenkov ring
$\rightarrow$ decay kinematics

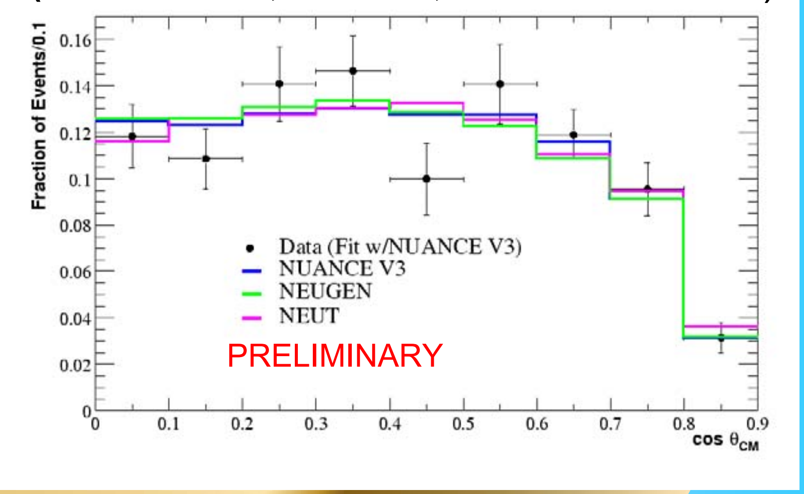
~5,000 NC π^0 events now
(~2,500 shown in these plots)

MC fits details of π^0 decays nicely

extracted signal π^0's in data & MC:



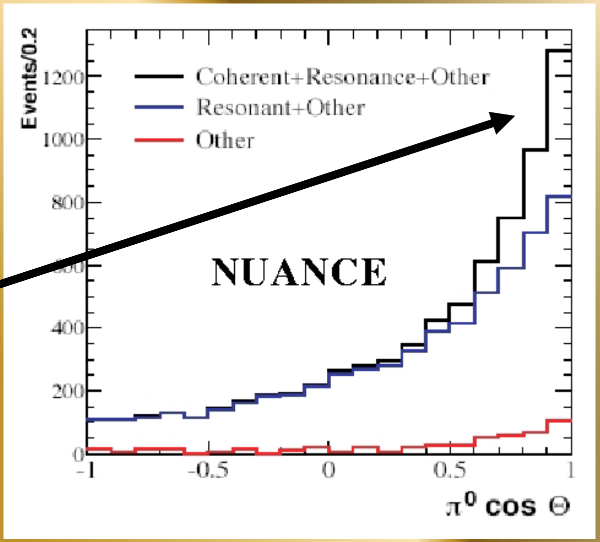
(**MiniBooNE**, **MINOS**, and **K2K** σ MCs)



understanding rate & kinematics of π^0 production important because background to $\nu_\mu \rightarrow \nu_e$ search

NC Coherent π^0 Production

π^0 angular distribution sensitive to mode of production



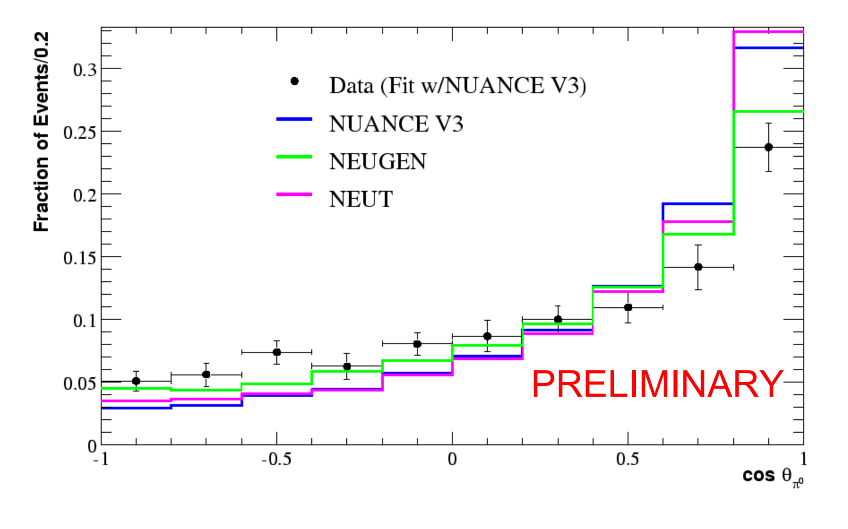
~ 80% of π^0's produced resonantly (Δ)
~ 20% coherent π^0 production

- scatter off entire nucleus
- forward scattered π (low Q^2)

- important for $\nu_\mu \rightarrow \nu_e$ search
  (coh predicted to be up to 20% of π^0 background)
- impacts ability to discern between $\nu_\mu \rightarrow \nu_s$ and $\nu_\mu \rightarrow \nu_\tau$ in atmospheric data

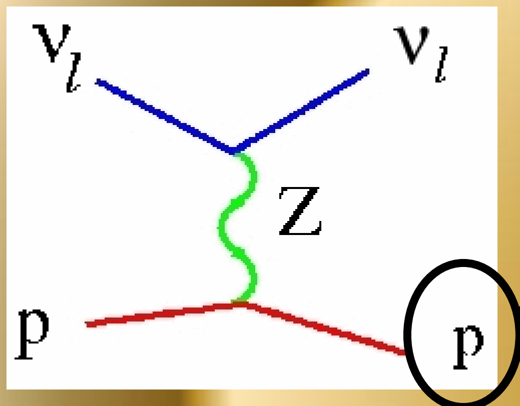
- no coherent π data below 2 GeV
- competing models differ by large factors

- important to understand how strongly coherent production contributes to overall NC π^0 rate at low E with MiniBooNE & K2K near detector data



Sam Zeller, PHENO, April 26, 2004

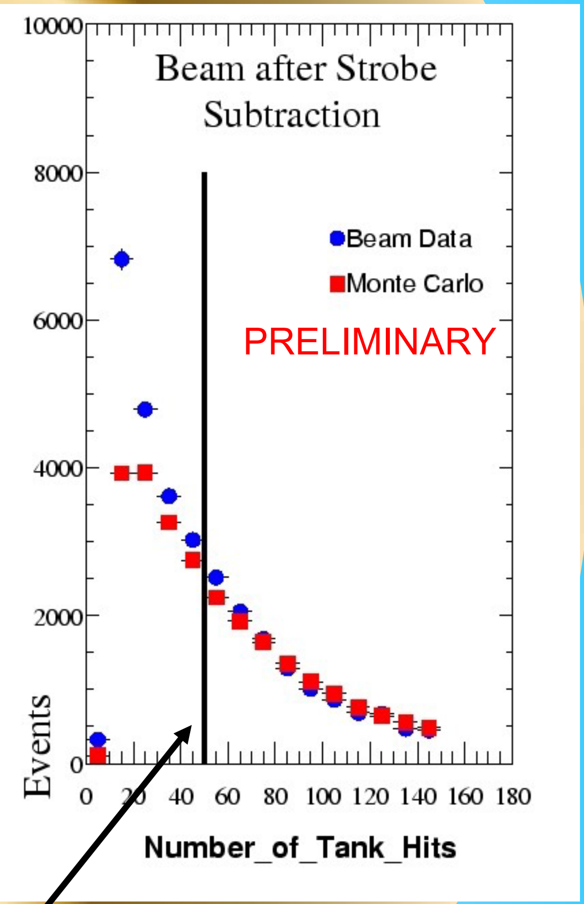
NC Elastic Scattering



$\nu_\mu \, p \rightarrow \nu_\mu \, p$

reconstruct proton E
from scintillation light

* 81% purity
* 68% efficiency



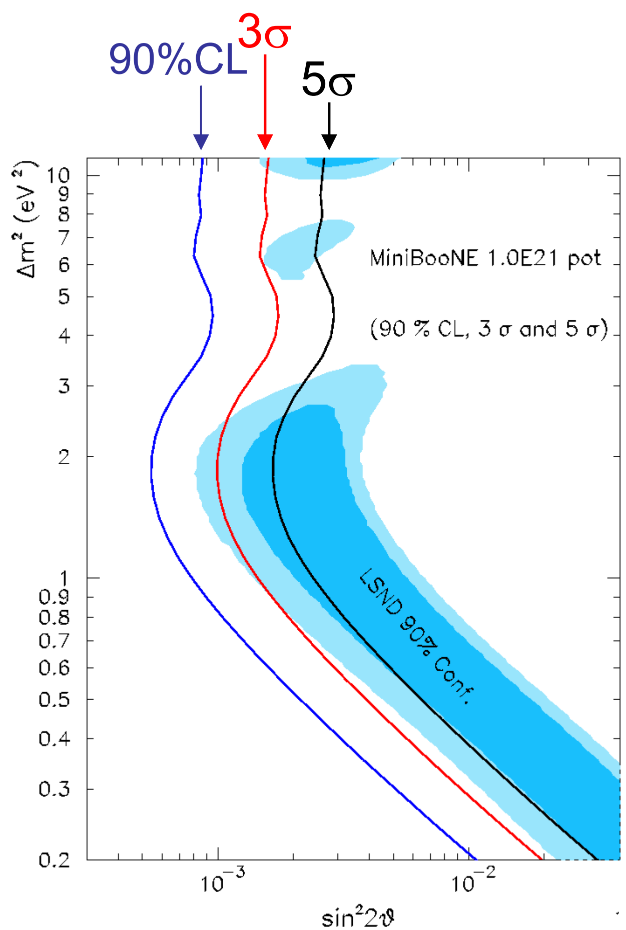
- low energy events (< 200 MeV)
- sensitive to optical model
  (useful for studying scintillation properties
  of oil & low energy response of detector)
- measure Δs (component of p spin carried by s quark)

Monte Carlo models data well down to ~60 tank hits = 150 MeV proton KE

Sam Zeller, PHENO, April 26, 2004

Updated MiniBooNE Sensitivity

detailed re-evaluation of ultimate sensitivity MiniBooNE can achieve



$\nu_\mu \rightarrow \nu_e$ oscillation search

contains our current best knowledge updated from MiniBooNE proposal

4-5 σ coverage of LSND 90% CL region with 1×10^{21} POT

to definitively exclude LSND in the event that MiniBooNE does not see a signal, we need 1×10^{21} POT

Conclusions

- **MiniBooNE has collected 2.3×10^{20} POT to date:**
  - ~260,000 ν's → roughly 25% of our desired final data sample
  - well in the process of calibrating and understanding our detector
  - first physics results on QE, NC π^0, and NC elastic event samples
    - interesting in their own right in addition to supplying information for oscillation analyses
    - large push to compare to other experiments' σ Monte Carlos
    - part of larger effort towards gaining an overall better understanding of low energy neutrino interactions (esp on nuclear targets)
    - MiniBooNE already has > an order of magnitude more events than previous bubble chamber experiments where most of our low E σ knowledge comes from
- **Outlook on anticipated oscillation results:**
  - ν_μ disappearance: expect first results later this year
  - $\nu_\mu \rightarrow \nu_e$: plan is to "open the box" sometime in 2005